

Contribution of N from green harvest residues for sugarcane nutrition in Brazil

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Abstract

Brazil is recognized as a prominent renewable energy producer due to the production of ethanol from sugarcane. However, in order for this source of energy to be considered truly sustainable, conservation management practices, such as harvesting the cane green (without burning) and retaining the trash in the field, need to be adopted. This management practice affects mostly the nitrogen (N) cycle through the effect of trash on immobilization-mineralization of N by soil microorganisms. The aim of the experiments reported here was to evaluate N recovery from trash (trash-N) by sugarcane during three ratoon crop seasons: 2007, 2008 and 2009. Two field experiments were carried out, one in Jaboticabal and the other in Pradópolis, in the state of São Paulo, Brazil. The experiments were set up in a randomized block design with four replications. Within each plot, microplots were installed where the original trash was replaced by trash labelled with ¹⁵N, and maintained up to the fourth crop cycle. Trash-N recovery was higher in the Jaboticabal site, the most productive one, than in the Pradópolis site. The average trash-N recovery across the two sites after three crop cycles was 7.6 kg ha⁻¹ (or 16.2% of the initial N content in trash), with the remaining trash-N being incorporated into soil organic matter reserves. While these results indicate that the value of trash for sugarcane nutrition is limited in the short term, maintaining trash on the field will serve as a long-term source of N and C for the soil.

Keywords: ¹⁵N, mineralization, nitrogen, *Saccharum spp*, sustainability, trash

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Introduction

Based on its positive energy balance, the sugarcane crop has been highlighted globally as an important feedstock for biofuel production (Renouf *et al.*, 2008; Cavalett *et al.*, 2011). With almost 9 million ha producing over 6.5 million tons of cane annually, Brazil is the largest producer of sugarcane in the world (CONAB, 2013).

In the main Brazilian region for production of sugarcane (Center South), there has been a steady increase in mechanical harvesting without prior burning resulting in large amounts of cane trash (straw, residue) being returned to the field. This practice of harvesting without prior burning is referred to as green cane trash blanketing (GCTB). During the crop season of 2013/2014, green harvesting was estimated to account for 85% of the cane harvested in Center South region.

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The amount of trash generated by GCTB harvesting of sugarcane can range from 10 to 20 Mg ha⁻¹ of dry matter (Trivelin *et al.*, 1995, 1996; Vitti *et al.*, 2011; Fortes *et al.*, 2012) and has the potential to increase soil organic matter content and release nutrients into the soil (Wood, 1991; Razafimbelo *et al.*, 2006; Robertson & Thorburn, 2007b; de Luca *et al.*, 2008). According to Carvalho *et al.* (2013), the main inputs of soil organic carbon (SOC) in sugarcane fields are derived from aboveground part of the plant (dry leaves and tops) rather than roots. These authors calculate that the total allocation to SOC (mean of four harvests from three areas) from above- and belowground compartments was about 1.1 Mg C ha⁻¹ yr⁻¹, of which 33% was from root system and 67% from trash.

However, sugarcane trash represents an important energy source, which can be used for electricity generation, steam production for the boilers, and in the future, as raw material for the second generation of ethanol production by means of enzymatic hydrolysis. For these

reasons, understanding the benefits of returning sugarcane trash to the field and knowing its effect on soil sustainability is important for the assessment of how much trash can be removed for energy production without causing further soil degradation.

Many benefits have been identified as a result of sugarcane trash being maintained in the field. For example, the enhancement of soil physical quality (Sparovek & Schnug, 2001), reduction in greenhouse gas (GHG) emissions (Figueiredo & La Scala, 2011), increase in carbon stocks (Cerri *et al.*, 2011) and of biological activity (Souza *et al.*, 2012), improvement of soil fertility (Vitti *et al.*, 2011), better nutrient cycling (Franco *et al.*, 2007) and higher yield and lifespan of sugarcane ratoons (Gava *et al.*, 2001) are all important issues that result from trash maintenance.

Among the nutrients released during trash decomposition, nitrogen (N) has been reported as one of the most important elements to be studied, due to its complex dynamics in plant–soil system (Trivelin & Franco, 2011). The availability of N from trash mineralization is dependent on factors such as temperature, moisture, soil aeration and chemical composition of trash, especially the carbon: nitrogen ratio (C : N). Thus, there are various interacting factors that control the rate of transformation of organic N to inorganic N (Janssen, 1996).

Sugarcane trash has typical carbon and nitrogen contents ranging from 390 to 450 g kg⁻¹ (carbon) and 4.6 to 6.5 g kg⁻¹ (nitrogen) (Ng Kee Kwong *et al.*, 1987; Oliveira *et al.*, 1999), thus having a C : N ratio of around 100 : 1. This high C : N ratio promotes substantial immobilization of N in the soil and results in only small amounts of nitrogen being mineralized for the following crop season (Gava *et al.*, 2001; Robertson & Thorburn, 2007a; Fortes *et al.*, 2012). Usually, N immobilization takes place in plant residues (trash) when N content is less than 18 g kg⁻¹ and the C : N ratio is higher than 20 (Smith & Douglas, 1971; White, 1984; Bengtsson *et al.*, 2003). Thus, in the short term, the nitrogen contribution from sugarcane trash is expected to be minor as immobilization will be substantial. Under such conditions, competition for the small amount of N available will occur between the roots and soil microorganisms (Jingguo & Bakken, 1997).

The contribution of N from trash is insignificant for nutritional purposes with only 4% of N being recovered from trash during the first ratoon under Brazilian field conditions (Vitti *et al.*, 2005). Further, Vitti *et al.* (2005) suggested that the majority of uptake of this trash-N occurred during the last months before sugarcane harvest. Thus, a significant contribution of N from sugarcane trash may occur during subsequent ratoons because more than 90% of trash-N remains in the soil. Robertson & Thorburn (2007b) verified that almost 80%

of trash-N still remained in the soil after 6 years of implementation of green harvest sugarcane management.

In the research reported in this study, the contribution to sugarcane nutrition of N from green harvest residues during three consecutive crop seasons in different environmental conditions is evaluated. Such studies are important because few data are available under the conditions prevailing in São Paulo state, Brazil. The use of data from other areas that experience different growing conditions to establish models and parameters about trash decomposition, N mineralization from trash and N-trash uptake by sugarcane may be inappropriate.

Materials and methods

Sites description

This study was carried out at two sites located near Jaboticabal city in the state of São Paulo, Brazil, on sugarcane fields that were harvested green without prior burning. Site 1 was located at the Santa Adelia Bioenergy farm (21°19' S, 48°19' W, 600 m asl), on a Typic Kandiudox (TK) with a medium texture (Soil Survey Staff, 2011). Site 2 was located at the São Martinho Bioenergy farm (21°17' S, 48°12' W, 580 m asl), on a Rhodic Eutrudox soil (RE) with clayey texture (Soil Survey Staff, 2011). The climate in both sites is classified as Aw (tropical or savannah), according to Köppen classification (Rolim *et al.*, 2007). Chemical soil attributes were determined in samples collected at 0–0.25 and 0.25–0.5 m, in order to determine lime, gypsum and fertilizer requirements to avoid nutritional limitations.

In Site 1, the tillage practices adopted were as follows: herbicide applications over the previous sugarcane ratoon, deep ploughing (depth of 0.4 m) to incorporate previous crop residues and 2 Mg ha⁻¹ of limestone into the soil, soil diskling (depth of 0.2 m) for final soil preparation before furrow opening (depth of 0.35 m) and planting. In Site 2, the practice adopted was reduced tillage by means of herbicide application over the old ratoon, soil subsoiling (depth of 0.35 m) followed by furrow opening (depth of 0.35 m) and planting.

The planting was performed in February 2005 in Site 2 and in April 2005 in Site 1. Sugarcane sets of SP813250 variety with 15 buds per metre of row were planted. A total of 80 kg ha⁻¹ of N as Urea, 120 kg ha⁻¹ of P₂O₅ as single superphosphate and 120 kg ha⁻¹ of K₂O as potassium chloride were applied at the bottom of each furrow. During the experimental period, weather data were measured by automatic weather stations located near to each experimental site. Climatological water balance was calculated according to the Penman–Monteith approach made by Allen *et al.* (1998) (Fig. 1).

Experimental design

After plant cane harvest (performed in July and August 2006, respectively, for the sites 1 and 2), the trials were set up in a randomized block design with four replications. The experimental

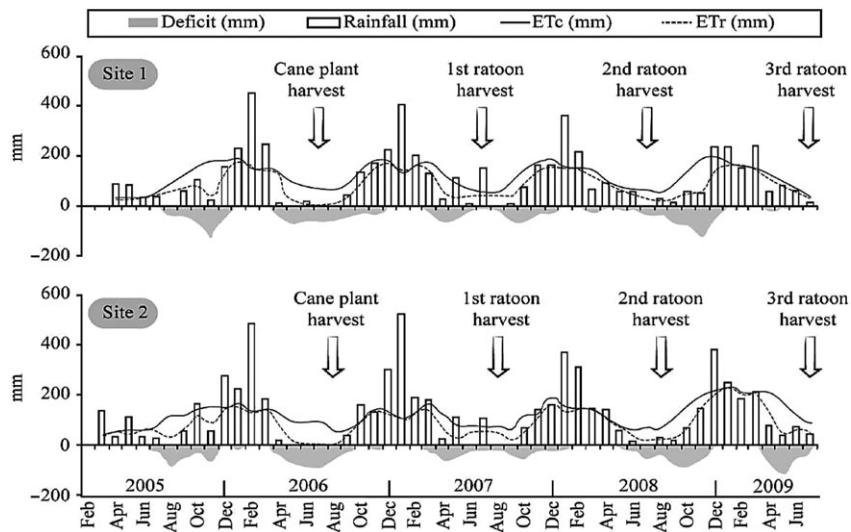


Fig. 1 Climatological water balance at sites 1 and 2 during the crop cycles. ETc, crop evapotranspiration; ETr, real evapotranspiration.

plots had 12 rows of sugarcane (1.5 m apart and 15 m long). In the centre of each plot, a microplot (3 m^2) was established (2 m long and 1.5 m wide). The trash present in each microplot was replaced by the same quantity of trash labelled with ^{15}N . The trash- ^{15}N (10 Mg ha^{-1} of dry matter) was deposited over the soil surface in October 2006. The trash- ^{15}N material, composed of dry leaves and tops of sugarcane, was obtained from another field experiment, where aboveground part of sugarcane was labelled by spray application of ^{15}N -urea solution according to the method of Faroni *et al.* (2007). Quantitative analysis performed on the trash material before its distribution at each site showed a biomass enrichment of 0.83 and 1.00% ^{15}N of atoms, and 51 and 41 kg ha^{-1} N for the sites 1 and 2, respectively.

Measurements

The harvest of the first ratoon took place in July (Site 1) and August 2007 (Site 2); the subsequent crop harvests were performed in July (2008 and 2009) for both sites.

During crop harvest, all the plants located in the microplots and in both adjacent rows were collected manually. The procedure adopted was the same described by Trivelin *et al.* (1994). The plants were separated into dry leaves, tops and stalks. The fresh biomass (kg) of each component was obtained directly in the field. The samples were then chopped in a forage chopper and homogenized, and a subsample of each component was weighed before being dried at 65°C for 72 h after which they were reweighed. The subsample was then further ground in a knives mill. Measurements of total N (%) and ^{15}N isotopic abundance (atom % ^{15}N) were taken in a mass spectrometer coupled with a N analyser, model ANCA-GSL, from Sercon Co., Crewe, UK (Barrie & Prosser, 1996).

After microplot evaluation, the entire plot was harvested mechanically to obtain industrial stalk yield. Following harvest, the microplots were maintained, and the 'new' trash

(unlabelled) was deposited over the trash- ^{15}N . This procedure was also adopted in the subsequent crop cycle. Nitrogen fertilization was not performed on the ratoon crops, to isolate the effect of the trash- ^{15}N recovery by sugarcane plants.

Nitrogen uptake and recovery

The N in plant from trash (NPFT) and recovery of ^{15}N -trash (RNT) by sugarcane aboveground biomass were estimated by the isotopic dilution approach using the following equations:

$$\text{NPFT} = [(A - C)/(B - C)].\text{NT} \quad (1)$$

$$\text{RNT} (\%) = (\text{NPFT}/\text{NAF}).100 \quad (2)$$

where NPFT = N in the plant from ^{15}N -trash (kg ha^{-1}); RNT – recovery of ^{15}N -trash by sugarcane (%); A – abundance of ^{15}N (% of atoms) in the plant; B – abundance of ^{15}N (% of atoms) in the source (^{15}N -trash); C – natural abundance of ^{15}N (0.366% of atoms); NT – N content in the plant (kg ha^{-1}); NAF – amount of N-trash applied (kg ha^{-1}).

Statistical analyses

The results were submitted to analysis of variance (ANOVA), using F-test at $P < 0.05$ level, the averages being compared by Tukey test at 5% of probability.

Results

Biomass and nitrogen accumulation

Comparing the two experimental locations, Site 1 showed higher aboveground biomass and N accumulation in 2008, 2009 and in the sum of three seasons

(2007/2009) (Fig. 2). However, there was no difference between sites for these parameters for the first year (2007). Similar results were measured for stalks biomass and N accumulation, which is not surprising as the majority of aboveground biomass would be comprised of stalks.

For the aggregated data from both sites, the total aboveground biomass production was lower in 2008 than those measured in 2007 and 2009, in which biomass yields were similar. On the other hand, N accumulation was higher in 2009, followed by 2007 and 2008 (Table 1). Stalks biomass showed an increase from the second to third year (2008–2009), which could be related to favourable seasonal conditions during the 2009 [third season when adequate rainfall was distributed throughout the growing period and especially for the months preceding sugarcane maturation (Fig. 1)].

Trash-N uptake and recovery by sugarcane

The trash-N uptake (NPFT) by aboveground biomass was higher in Site 1 compared with Site 2 for 2008, 2009

and in the sum of three seasons (2007/2009) (Fig. 3). For RNT, the same trend was verified only in 2008 and with the combined data across 2007–2009. In Site 1, the NPFT in aboveground part of sugarcane was 3.7 (2007), 1.3 (2008) and 4.4 (2009) kg ha⁻¹, corresponding to 7.3, 2.5 and 8.7% RNT. In Site 2, NPFT for the same period was 2.4, 0.7 and 2.6 kg ha⁻¹ (5.9, 1.6 and 6.3% RNT).

For the aggregate data, differences were observed in aboveground relating to NPFT and RNT in 2007 and 2009 (Table 2) and the same trend was apparent for the stalk component. At the end of the experimental period, the total NPFT was 7.6 kg ha⁻¹, corresponding to 16.2% RNT, which represents only 2.1% of total N accumulated by the crop.

Discussion

The RNT varied from 5 to 8% at the end of the first ratoon cycle (2007) at both sites (Fig. 3), similar to those presented by Ng Kee Kwong *et al.* (1987) and Gava *et al.* (2003). The NPFT on tops was higher at Site 1 than Site 2, although the biomass and N accumulation were the

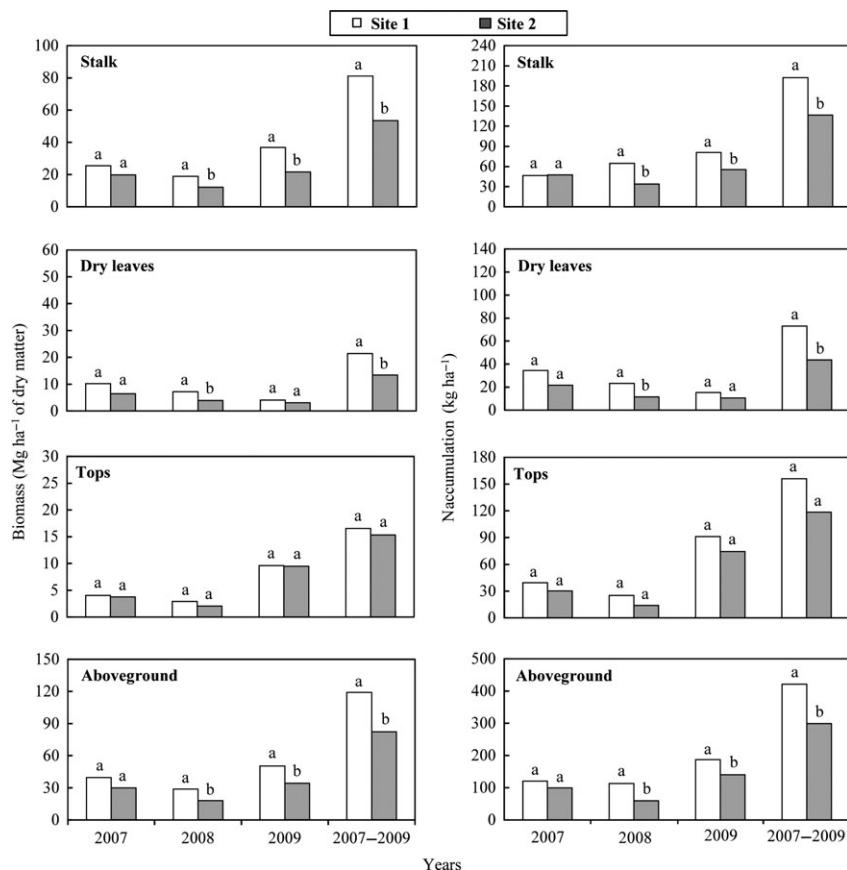


Fig. 2 Biomass and N accumulation in sugarcane components (stalk, dry leaves, tops and aboveground part) throughout three crop seasons in two experimental sites in Brazil (1 and 2). Same letters indicate no difference between sites in each year according to Tukey's test ($P < 0.05$).

Table 1 Biomass and N accumulation in parts of sugarcane plant during three crop season. (All data are the average across sites*)

Year	Biomass				N accumulation			
	Stalk	Dry leaves	Tops	Aboveground	Stalk	Dry leaves	Tops	Aboveground
	Mg ha ⁻¹ of dry matter				kg ha ⁻¹			
2007	22.6 ab	8.3 a	3.9 b	34.8 a	34.8 a	28.1 a	34.8 b	110.0 b
2008	15.5 b	5.5 ab	2.5 c	23.6 b	23.6 b	17.3 b	19.6 c	86.3 b
2009	29.2 a	3.6 b	9.5 a	42.3 a	42.3 a	12.9 b	82.8 a	163.9 a
2007–2009	67.4	17.4	15.9	100.7	164.6	58.3	137.2	360.5
LSD	9.4	3.3	0.5	11.2	17.8	9.5	7.7	24.2
CV (%)	14.5	19.7	3.5	11.4	11.4	16.9	5.8	6.9

LSD, least significant difference; CV, coefficient of variation.

*Values followed by same small letters in column indicate no difference between years according to the Tukey' test ($P < 0.05$).

same. No differences were detected between sites for all the other parameters evaluated. Among the plant components, stalks showed greater recovery when compared to tops and dry leaves. The higher N recovery in stalks was probably associated with the period of measurement, carried out during the sugarcane maturation phase, when stalks make up the bulk of the biomass (Table 1). At this stage, leaves constitute only 10% of plant biomass (Robertson *et al.*, 1996; Franco *et al.*, 2013). Furthermore, later in the season, part of the N from the senescent leaves is expected to be remobilized to the active parts of the plant (stalks).

In the second ratoon season (2008), even though differences occurred between sites for NPFT and RNT on aboveground biomass, it is possible to observe a sharp decrease in the amount of trash-N recovery by plants, especially in Site 2 (Fig. 2) which may be explained by the lower dry biomass and N accumulation obtained at this site in 2008 when compared with the previous season (Fig. 2) which was most likely associated with less favourable seasonal conditions.

The rainfall during 2nd ratoon (2008) at Site 2 was almost 350 mm lower than for the first ratoon (1729 mm in 2007 against 1371 mm in 2008), which affected the biomass production and ¹⁵N-trash recovery. Further, the reduction in ¹⁵N-trash recovery may also be associated with low temperature average during 2008 compared to 2007 (25.7 in 2007 against 23.3 °C in 2008). Temperature has important implications for determining microorganism activities, and therefore trash mineralization (Stanford *et al.*, 1973; Katterer *et al.*, 1998). Stanford *et al.* (1973) reported that, in the temperature range from 5 to 35 °C, the rate of N mineralization doubles for each 10 °C increase in temperature. In other work, Lara Cabezas *et al.* (2004) showed that high temperature and moisture levels in the soil favour crop residues mineralization, while Torres *et al.* (2005) reported a decrease in the decomposition rate and N release from cover crops residues under low temperature and moisture.

The unfavourable water balance in the 2nd ratoon (2008) has also affected the sugarcane yield in Site 1 (Fig. 2). Nevertheless, biomass and nitrogen accumulation reduction were not as remarkable as those observed in Site 2. However, during the 2009 season (3rd ratoon), better seasonal conditions for plant growth resulted in higher biomass production, N accumulation and hence the increases in NPFT and RNT at both sites (Fig. 3). Furthermore, the rate of 7.5% of RNT in the third year may indicate a decrease in the C : N ratio of trash, considering that at the start of the experiment, this ratio was around 100 : 1, which would certainly cause immobilization of N by microorganisms (Jadhav, 1996; Bengtsson *et al.*, 2003). However, Fortes *et al.* (2012) found a reduction in the C : N ratio from 108 : 1 to 24 : 1 during the years of evaluation (three ratoons), at the Site 2 experiment, resulting in 31% of trash-N being released to the soil.

Interestingly in 2009, significant differences between the sites were measured only with the tops, which showed higher NPFT and RNT at Site 1. This resulted in the same trend with aboveground trash-N recovery as in the previous seasons (Fig. 3). The influence of tops on aboveground NPFT is due to the huge increase in tops biomass in 2009 when compared with 2008. Tops biomass in 2009 represented 22.5% of total aboveground biomass (Table 1).

At the end of the experimental period, the differences found represent 3.7 kg ha⁻¹ more NPFT by plants at Site 1 than Site 2, which represents 24.9% more N from trash (Fig. 3). These results are due to the higher biomass production in Site 1 than Site 2 (119 vs. 82 tonnes ha⁻¹) (Fig. 2), resulting in 29% more N accumulation in Site 1. The lower biomass production at Site 2 may be attributed to the reduced tillage adopted prior the sugarcane planting and to water deficit during the ratoon crop cycle. Regardless reduced tillage provides an effective means to conserve overall soil fertility, even though it may initially increase the need for N fertilizer

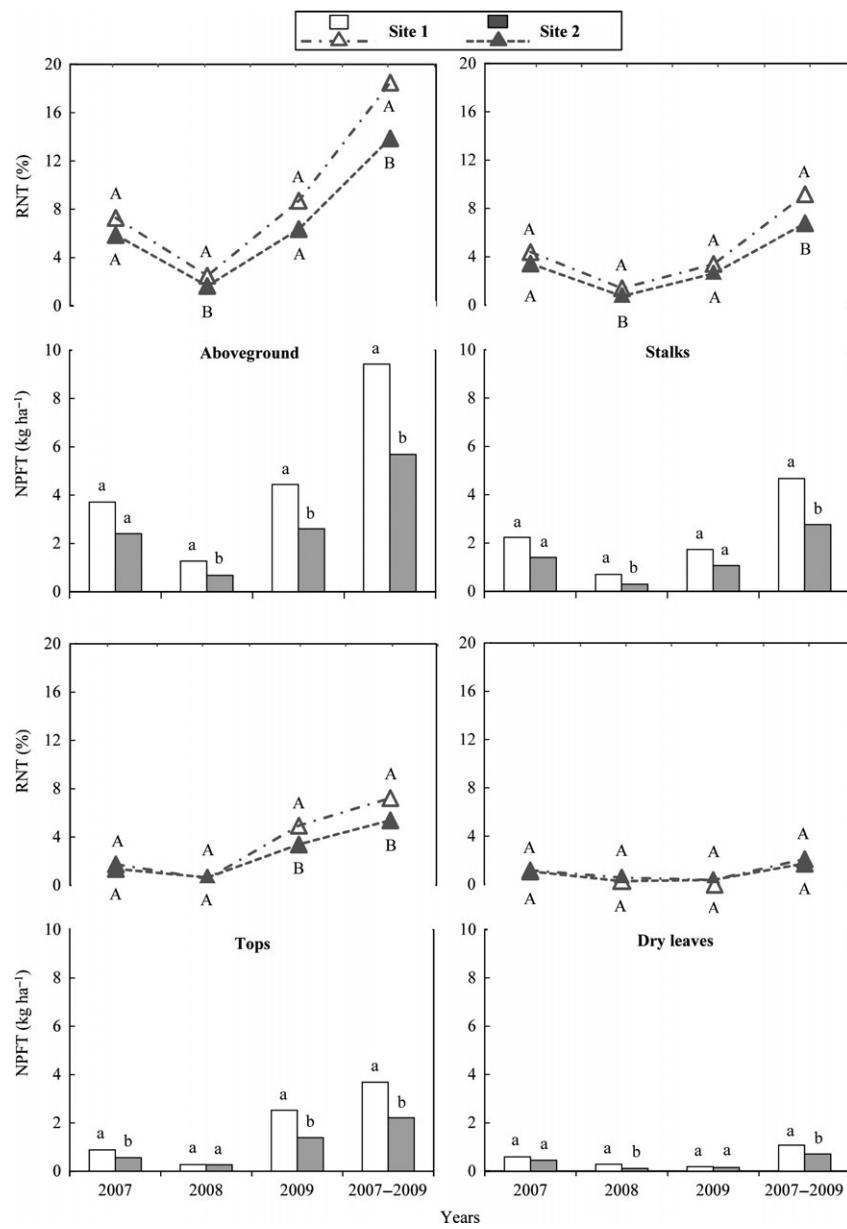


Fig. 3 Recovery of N from trash (RNT, %) and nitrogen in plant from trash (NPFT, kg ha^{-1}) in sugarcane components (stalk, dry leaves, tops and aboveground part) throughout three crop seasons in two experimental sites in Brazil (1 and 2). Same letters indicate no difference between sites in each year according to Tukey's test ($P < 0.05$).

(Maltas *et al.*, 2013), particularly if the trash has a high C : N ratio, as is the case with sugarcane trash. Further, in these studies N fertilization was not carried out with the ratoon crops.

Averaged across the two sites after three crop cycles, only 16.2% of N-trash was recovered by sugarcane (Table 2), which represents a small contribution to crop nutrition (2.1% of total N needs) in the short term. The remainder was most likely located in the various nitrogen pools known to exist in the soil/plant continuum associated with the dynamics of nitrogen movement

between different pools in the soil. Myers *et al.* (1994) reported that, during the decomposition of the crop residues, there is partitioning of N into the compartments of mineral N (soil and fertilizer), humic N and immobilized N due to the soil microbial biomass, with a continuous turnover of this N among the compartments.

If the initial trash composition for Site 2 (C : N ratio of 108) described by Fortes *et al.* (2012) is taken into account and calculations proposed by Robertson & Thorburn (2007b) are applied, 98 and 120 kg ha^{-1} N

Table 2 Nitrogen in plant from trash (NPFT) and recovery of N from trash (RNT) in each part of sugarcane over the experimental period. (All data are the average across sites*)

Year	NPFT				RNT			
	Stalk	Dry leaves	Tops	Aboveground	Stalk	Dry leaves	Tops	Aboveground
	kg ha ⁻¹				%			
2007	1.8 a	0.5 a	0.7 b	3.1 a	3.9 a	1.1 a	1.5 b	6.6 a
2008	0.5 b	0.2 b	0.3 c	1.0 b	1.1 b	0.4 b	0.6 c	2.1 b
2009	1.4 a	0.2 b	1.9 a	3.5 a	3.0 a	0.4 b	4.2 a	7.5 a
2007–2009	3.7	0.9	2.9	7.6	8.0	1.9	6.3	16.2
LSD	0.8	0.2	0.2	1.0	1.9	0.4	0.5	2.4
CV (%)	22.0	21.4	8.4	14.3	24.2	23.4	8.5	15.1

LSD, least significant difference; CV, coefficient of variation.

*Values followed by same small letters in column indicate no difference between years according to the Tukey' test ($P < 0.05$).

would be immobilized to achieve trash decomposition in sites 1 and 2, respectively. This means 57–69 kg ha⁻¹ N needs to be supplied by soil organic N or fertilizers inputs. Thus, in order to ensure high sugarcane yield and avoid soil fertility depletion, the rate of fertilizer N needs to be increased at least for the early years of sugarcane green harvest as an increase N immobilization will most certainly occur due to the high C : N ratio of the trash.

However, although sugarcane trash only provides a small amount of N for the crop during the first years of green harvest establishment, the trash deposition on soil surface by successive harvests should contribute towards a greater accumulation of organic N into the soil. According to Robertson & Thorburn (2007b), around 79% of the trash-N may be retained in the soil in the long term under sugarcane green harvesting systems. Simulation studies performed in Australia indicate that after 20 years of sugarcane trash retention, it is possible to save around 40 kg ha⁻¹ N per year in fertilizer N due to long-term N mineralization of sugarcane (Vallis *et al.*, 1996). Simulations performed for Brazilian conditions resulted in similar findings (Trivelin *et al.*, 2013). However, it is important to note that all of the data currently available (Vallis *et al.*, 1996 included) are based on trash incorporation between sugarcane cycles and not on continuous deposition onto the soil surface. Adopting the latter approach may well result in substantially more N accumulation over time.

In our experiments, sugarcane absorbed 7.6 kg ha⁻¹ of N (means of two sites) from trash after 3 years of maintenance in the field (representing 16.2% of the initial N content of trash) (Table 2). The results indicate that the most part of trash-N remains in the soil and serves as a long-term source of N to the crop, as well as an important source of soil organic carbon. This finding is important considering the interest of farmers in removing trash from fields for energy purposes. Based

on our results, as the trash only provides 2.1% of total N needs, its removal will not affect sugarcane nitrogen nutrition in the short term, but is likely to show a potential negative effect in the long term for sugarcane nutrition and soil C sequestration.

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